PWGSC Contract No. W7711-7-7420/A
on behalf of
DEPARTMENT OF NATIONAL DEFENSE

RESEARCH AND DEVELOPMENT OF AN ADVANCED PERSONAL LOAD CARRIAGE MEASUREMENT SYSTEM: Phase IV: Section A

Executive Summary
Measurement Systems for Assessment of Personal Load Carriage Systems

December 1998

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RESEARCH AND DEVELOPMENT OF AN ADVANCED PERSONAL LOAD CARRIAGE MEASUREMENT SYSTEM

Phase IV: Section A

Executive Summary
Measurement Systems for Assessment of Personal Load Carriage Systems

by

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Abstract

The Defence and Civil Institute of Environmental Medicine (DCIEM) contracted Queen's University to assist in the research and development of an Advanced Personal Load Carriage System (APLCS) in support of two Canadian Forces Soldier Modernization Programs: major crown project D6378 called Integrative Protective Clothing and Equipment (IPCE), and major crown project L2646 called Clothe the Soldier (CTS) Project. In 1995, Queen's University undertook to develop standardized assessment tools as a cost effective and reliable method by which various load carriage equipment designs and components could be tested, evaluated and approved for further military evaluations with representative users in the field. Under the IPCE project, Phases I-III involvement primarily development and validation of the measurement system. Further testing took place to evaluate and improve the prototype CTS load carriage system, add to the research data base and enhance knowledge of pack designs. Each of these projects will be described briefly with relevant outcomes identified. The current contract entitled: Research and Development of an Advanced Personal Load Carriage Measurement System: Phase IV was to improve measurement components and provide sole source ownership to DCIEM, and to develop a further understanding of specific factors that affect load carriage ability. The purpose of the Executive Summary Report is to summarize and document work to date so that DCIEM is aided in the decision-making process for future developments in the area of load carriage.

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EXECUTIVE SUMMARY

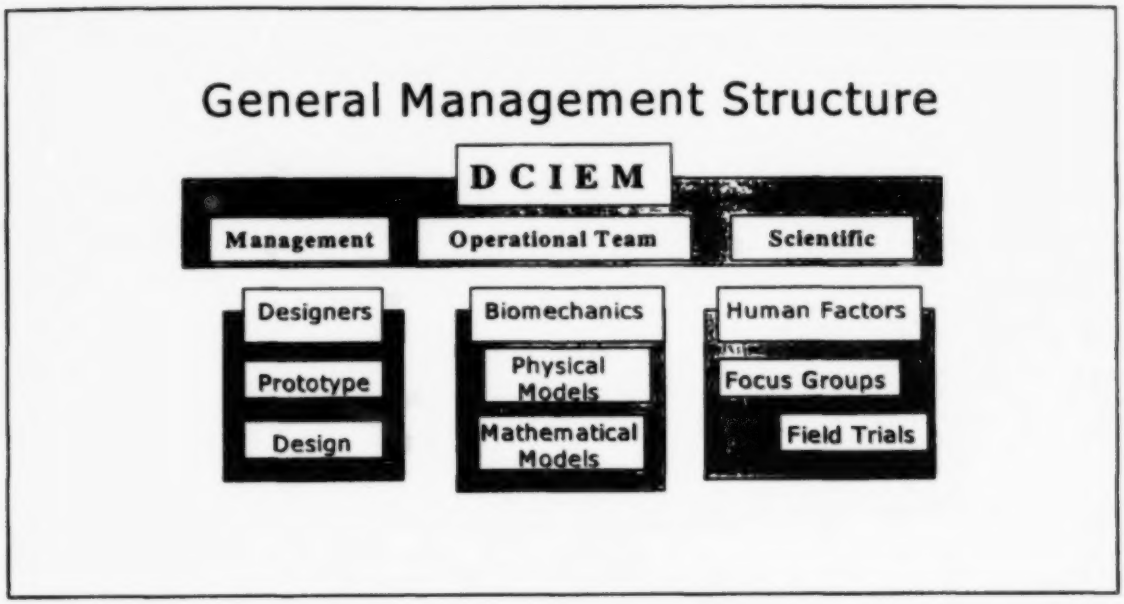
Advancements in Measurement Systems for Assessment of Personal Load Carriage Systems

1.0 Introduction

It is recognized that soldier survival, sustainability, and performance in the field will often require carrying significant loads consisting of protective equipment, armaments and probation for any future conflict or peacekeeping operations. It is also recognized that soldier survival may depend on carrying heavy loads over greater distances or moderate loads over shorter distances, but where soldier performance is essential. Therefore, the next generation of Personal Load Carriage Systems (PLCS) should be designed to be compatible with the range of soldier physical, physiological and biomechanical capabilities for survival, as well as optimize soldier performance and operational effectiveness. To protect soldiers in this manner, it is necessary to modernize the soldier system in order to protect the soldier and equipment under diverse conditions.

The Defence and Civil Institute for Environmental Medicine (DCIEM) has contracted Queen's University to assist in the research and development of an Advanced Personal Load Carriage System (APLCS) as part of a Canadian Forces Soldier Modernization Program, a major crown project D6378 Integrative Protective Clothing and Equipment (IPCE). This project is a long range NATO soldier modernization plan in which many NATO countries are involved. In addition to this next century project, another major crown project L2646 Clothe The Soldier (CTS), has been commissioned to satisfy immediate needs for personal protective clothing and equipment. Since replacement components are needed as soon as possible the CTS project, and eventually the IPCE requirements, necessitate a cost effective and reliable method by which various load carriage equipment designs can be tested, evaluated and approved for further military field trials. The overall objective of this study is to develop a valid and reliable

measurement system which can be used to evaluate design for the "Clothe The Soldier (CTS)" project and appraise procurement items for the Integrative Protective Clothing and Equipment (IPCE) project. The CTS project has been iteratively developing and designing a PLCS through a DCIEM design team consisting of a designer and manufacturer (Ostrom Outdoors Inc.), biomechanical evaluation and standardized testing (Queen's University), human factors specialists, (Human Systems Inc.) and important military portfolios; such as, Directorate of Land Requirements, Directorate of Soldier Systems Procurement Management and DCIEM. Through both the IPCE and CTS programs, biomechanical evaluation and standardized testing equipment and protocols have been developed and applied to provide DCIEM with standardized tools and assessment strategies that are valid and reliable. In addition, the tools have been used to examine many design questions, such as the location of shoulder strap attachment points and effectiveness of rods to stiffen the frame and create a dynamic suspension system. A conceptual approach to Advanced Personal Load Carriage Systems (APLCS) is given in Figure A1-1 as an overview of the process used within this phase of the contract.



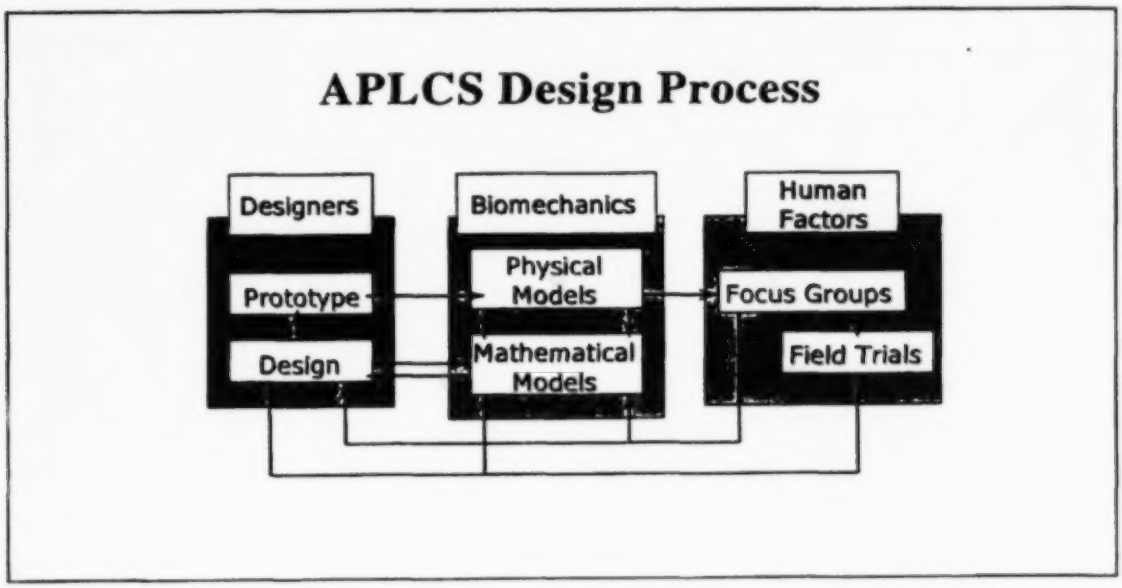


Figure 1-1. Approach used to accomplish both CTS and IPCE project demands for research, development and testing.

2.0 Summary of Earlier Reports and Publications

This Summary is written to provide an overall perspective of progress throughout all contracts within the IPCE and CTS programs. Through this approach, readers can more easily understand the steps taken and future directions that are recommended. The primarily references identified will be previous contract reports and publications presented at conferences.

2.1 Phase I: Research and Development of an Advanced Personal Load Carriage System (D.S.S. Contract # W7711-4-7225/01-XSE, 1995)

2.1.1 Review of Literature

The first phase of the R & D into Advanced Personal Load Carriage Systems (APLCS) involved a thorough study of the literature (Section A). This review highlighted the difficulty of developing assessment criteria and performance measures when one uses subject testing alone because of the variability in human body traits and diversity of subjective responses to discomfort under load carriage conditions. In addition, it was noted that not all biological measurements are able to address load carriage design questions. Biomechanical measures were most closely associated with subjective comfort scores with physiological measures being more sensitive to load and testing conditions. Subjective data were always helpful, especially for aspects related to design features. This led to the recommendation that a systems approach to load carriage was critical to capture all aspects needed in the design phase.

Technical Reports

Pelot, R.P., Stevenson, J.M.S., Reid, S., Barrick, C.M., and Day, J. Background Document for Advanced Personal Load Carriage Systems for Canadian Armed Forces. DSS Contract # W7711-4-7225/01 (112 pgs). 1995.

Stevenson, J.M., Bryant, J.T., dePencier, R.D., Pelot, R.P., and Reid, J.G. Research and Development of an Advanced Personal Load Carriage System (Phase I). DSS Contract # W7711-4-7225/01-XSE (Section A - 18 pgs). 1995.

Conference Proceedings

Stevenson, J.M., Barrick, C.M., Andrews, D.M., and Pelot, R.P. Limitations of Human Load Carriage. TTCP-TLG-8 and DCIEM Workshop, p. 5-7, Kingston, Canada, October 1996.

2.1.2 Development of Measurement Systems: Phase I

All three currently used measurement systems were developed under D.S.S. Contract # W7711-4-7225/01-XSE, 1995), however each device has been developed further in subsequent contracts. The three objective devices were: the LC Simulator, LC Compliance Tester and Load Distribution Manikin. The validation strategy was developed by soldiers wearing the same LC systems and asked to provide subjective and some objective measures during First Assessment and Standardized Testing (FAST) Trials. These FAST trials were based on asking subjects to complete a 5 km march with a 32 kg load interrupted by specific tasks involving load control (e.g., balance, ability) and load transfer (e.g., branch duck, marching). Five systems were tested, three military systems and two civilian systems, and first estimates of lumbar and shoulder reaction forces were suggested based on soldier discomfort scores.

Technical Report

Stevenson, J.M., Bryant, J.T., DePencier, R.P., Pelot, R.P., and Reid, J.G. Research and Development of an Advanced Personal Load Carriage System: Section A, B, C (Phase I). DSS Contract # W7711-4-7225/01-XSE 29 (Section B, 117 pgs). 1995.

Conference Proceedings

Bryant, J.T., Reid, S.A., Stevenson, J.M., dePencier, R., Saunders, G., Siu, D., and Doan, J. Development of a Design Assessment Protocol for Load Carriage Systems. TTCP-TLG-8 and DCIEM Workshop, p. 22-24, Kingston, Canada, October 1996.

Reid, S.A., Bryant, J.T., Stevenson, J.M., dePencier, R.D., Pelot, R.P., Reid, J.G., and Doan, J.E.B. Integration of Subjective and Objective Analysis Systems into a Standardized Measurement Approach. TTCP-TLG-8 and DCIEM Workshop, p. 24-26, Kingston, Canada, October 1996.

Doan, J.E.B., Stevenson, J.M., Bryant, J.T., MacNeil, S.K., and Day, J. Human Trials Testing of Load Carriage Designs. TTCP-TLG-8 and DCIEM Workshop, p. 16-17, Kingston, Canada, October 1996.

Bryant, J.T., Stevenson, J.M., Pelot, R.P., and Reid, J.G. Factors Affecting Load Carriage Performance. Proceedings of the Canadian Society of Biomechanics, p. 324-325, Vancouver, British Columbia, 1996.

2.1.3 Design Analysis of Load Carriage

In Section C of the report, the current state of the art of load carriage is documented. It was apparent from the design features that the civilian systems had surpassed the military systems. Pack features and functions were documented and from these data, recommended design guidelines were suggested. A preliminary design concept called Concept I was described and sketched to illustrate the application of state of the art means and guidelines to meet current military needs.

Technical Report

Stevenson, J.M., Bryant, J.T., DePencier, R.P., Pelot, R.P., and Reid, J.G. Research and Development of an Advanced Personal Load Carriage System: Section C (Phase I). DSS Contract # W7711-4-7225/01-XSE 29 (Section C, 82 pgs). 1995.

2.1.4 Validation of the Load Carriage Simulator

The LC Simulator was the main measurement tool being used in the development of objective performance criteria. It was necessary to validate the LC Simulator measurements under both static and dynamic conditions, and to conduct a sensitivity analysis on the accuracy of the biomechanical model used to evaluate shoulder and lumbar forces. Independent assessment tools were used to validate objective measures (e.g., Optotrack™ and Instrom™ used to validate Fastrak™ and strain gauges respectively). For the biomechanical model, two independent methods were used to determine the coefficient of friction values for shoulder strap forces.

Technical Report

Stevenson, J.M., Bryant, J.T., and Reid, S.A. and Pelot, R.P. Validation of the Load Carriage Simulator: Research and Development of an Advanced Personal Load Carriage system: Section D (Phase 1). DSS Contract #W7711-4-7225/01-XSE (44 pgs), 1996.

Published Proceedings

Stevenson, J.M., Bryant, J.T., Reid, S.A., Doan, J.B. DePencier, R., Saunders, G., Siu, D. Design and validation of measurement systems for load carriage. Advances in Occupational Ergonomics and Safety, (edited Das and Karwoski) IOS Press Inc., Virginia, p. 189-192,1997.

Conference Proceedings

MacNeil, S.K., Bryant, J.T., and Stevenson, J.M. A Biomechanical Model of Load Carriage. TTCP-TLG-8 and DCIEM Workshop, p. 20-21, Kingston, Canada, October 1996.

MacNeil, S., Bryant, J.T., Stevenson, J.M., and Reid, J.G. A Biomechanical Model of Load Carriage. Proceedings of the Canadian Society of Biomechanics, p. 322-323, Vancouver, British Columbia, 1996.

2.2 Phase II & III: Research and Development of an Advanced Personal Load Carriage System (D.S.S. Contract # W7711-4-7225/01-XSE, 1995)

2.2.1 SECTION A: Further Developments of the Load Carriage Systems

The first prototype meaurement systems were considered valid but there were many aspects that needed improvement. The improvements to the LC Simulator included: 1) improved software with more features under software control, 2) better feedback systems to regulate air flow to the pneumatic cylinders, 3) addition of a load cell to measure moments and forces at the *L4/L5* joint, 4) improved capacity in pressure measurements, and 5) anthropometric manikins representing body sizes from 5th and 50th percentile females to 50th and 95th percentile males and coated with Bocklite™ to represent synthetic skin. The Load Carriage Compliance Tester was improved by adding functions for lateral bending and flexion extension. In addition, a pack parts tester was developed as well as software to determine optimal kit placement. As a demonstration, a portable system for in-field measurements of biomechanical and physiological variables was developed with applicability to human field measurements.

Technical Reports

Reid, S.A, Doan, J.B, Bryant, J.T. Morin, E. Siu, D. Pelot, R.P. SECTION A: Further Measurements of Comprehensive Measurement Systems. Research and Development of an Advanced Personal Load Carriage System (Phase II and III). Contract #W7711-5-7273/001-TOS (42 pages), 1997.

Conference Proceedings

Stevenson, J., Bryant, T., Pelot, R., Morin, E., dePencier, R., Reid, G., and Deakin, J. Queen's Approach to Advanced Personal Load Carriage Systems. TCP-TLG-8 and DCIEM Workshop, p. 2-3, Kingston, Canada, October 1996.

2.2.2 SECTION B: Evaluation of Pack-Based Systems Using Comprehensive LC Measurement Systems:

This aspect involved LC Simulator and LC Compliance Tester of pack-based systems in order to expand the sample validation of pack-based systems. Over the course of this study, seven (7) systems were evaluated but only four (4) were assessed under all conditions on the LC Simulator and LC Compliance Tester. Selected sub-studies were conducted on the Load Carriage Vest (LCV) versus webbing, and on the impact of the Fragmentation Vest worn over LCV or Webbing. Two (2) pack-based systems were tested across all different anthropometric manikin sizes and four (4) systems were tested about all three axes of rotation on the Load Carriage Compliance Tester.

Technical Reports

Stevenson, J.M., Bryant, J.T. Reid, S.A, Siu, D. SECTION B: Analysis of Base Systems Using Standardized Measurement Simultators. Research and Development of an Advanced Personal Load Carriage System (Phase II and III). Contract #W7711-5-7273/001-TOS (77 pages), 1998.

Published Proceedings

Doan, J.B., Stevenson, J.M., Bryant, J.T., and Deakin, J.M. Human factors testing of load carriage designs. Advances in Occupational Ergonomics and Safety, (edited Das and Karwoski) IOS Press Inc., Virginia, p.193-196, 1997.

Rigby, W.A., Bryant, J.T., Reid, S.M., Doan, J.B. Stevenson, J.M. Analysis of load carriage systems using system compliance measures. Advances in Occupational Ergonomics and Safety, (edited, Kumar) IOS Press Inc., Virginia, p.308-311, 1998.

Doan, J.B., Bryant, J.T., Reid, S.M., Stevenson, J.M., Rigby, W.A., Andrews, D. Function testing of military load carriage subsystems. Advances in Occupational Ergonomics and Safety, (edited, Kumar) IOS Press Inc., Virginia, p.707-710, 1998.

2.2.3 SECTION C: Evaluations of Pack-Based Systems using the FAST Trials

This aspect involved expansion of the FAST human trials in an effort to validate the expanded sample of pack-based systems. Over the course of this study, seven (7) pack-based systems were evaluated in configurations of marching orders and battle orders during FAST trials. In addition, the cost of wearing a fragmentation vest as part of standing orders was assessed through subjective, physiological and performance measures.

Technical Report

Doan, J., Stevenson, J.M., Bryant, J.T. Morin E., Andrews, D. SECTION C: Analysis of Seven Pack-Base Systems Using Human FASTS Trials. Research and Development of an Advanced Personal Load Carriage System (Phase II and III). Contract #W7711-5-7273/001-TOS (72 pages), 1998.

2.2.4 SECTION D: Development of Acceptance Criteria for Physical Tests of Load Carriage Systems.

The principal aim of this section was to validate the objective measures from the LC Simulator and LC Compliance Tester by comparison to human FAST trials. A matrix of 76 variables (39 from LC Simulator and 37 from LC Compliance Tester) were compared to 39 physical measures from FAST trials. A correlation matrix was used to identify significant relationships at $p<0.05$ and these were used to identify the 10^{th} and 90^{th} decile of the benchmark pool. Linear regressions analyses were used to assist in defining threshold limit values (TLV) focused on perceived discomfort scores. It was recommended that 20KPa TLV be used to reduce the shoulder discomfort.

Technical Report

Bryant, J.T. Stevenson, J.M., Reid, S.A, Doan, J., Rigby, A. SECTION D: Development of Acceptance Criteria for Physical Tests of Load Carriage Systems. Research and Development of an Advanced Personal Load Carriage System (Phase II and III). Contract #W7711-5-7273/001-TOS (27 pg), 1997.

2.2.5 SECTION E: Phase I of Parametric Analysis of Advanced Personal Load Carriage Systems:

Parametric analysis allows for the understanding between system design characteristics and the impact of these design features on the bearer. A study of user kit placement was taken in order to identify soldier preferences and frequency of use. Kit input boundaries were established for a future optimization algorithm for biomechanical modelling which included kit and kit placement.

Technical Report

Pelot, R.P. Pinter, J., Stevenson, J.M., Bryant, J.T. Hall, C., Day, J. SECTION E: Phase I of Parametric Analysis of Advanced Personal Load Carriage Systems. Research and Development of an Advanced Personal Load Carriage System (Phase II and III). Contract #W7711-5-7273/001-TOS (49 pgs), 1997.

2.2.6 SECTION F: Development of Calibration Jig for Tekscan™ System

A local calibrator jig capable of applying known levels of load to known locations in the shoulder area will be built. Spatial orientation of the resulting normal forces in the shoulder region will be determined using a digitizing system. With this local calibrator, improved pressure measurement resolution can be achieved.

2.3 Clothe the Soldier Contracts

2.3.1 Investigation of Pack-Based Systems

A series of contracts were awarded to the Queen's University to assist with the design process of the new Clothe the Soldier program. The Clothe the Soldier program involved an integrated design and scientific assessment team managed by DCIEM and led by Major L. Bossi. The process included a number of assessments of civilian and military systems on the LC Simulator and LC

Compliance Tester in order to understand their design in terms of load control (e.g., balance and muscular requirements) and load transfer from the pack suspension system to the manikin (e.g., pressure and relative pack-person motion). The packs assessed were:

1) Osprey Vector One Silhouette 70
2) Syncron Norrona para Ranger 135L
3) Dana Designs ArcFlex Astral Plane
4) Arc'Teryx Bora 95
5) Ostrom/CTS Prototype M1
6) Ostrom/CTS Prototype K1
7) Ostrom/CTS Prototype Penultimate

These packs were added to the objective measures database in order to increase the numbers in the sample. In total, the database was increased to seventeen (17) pack-based systems. The report included each pack's ranking on the outcome variables that were significantly correlated to soldiers' perceptions from Phase II and III of the IPCE contract.

Technical Reports

Bryant, J.T., Stevenson, J.M., Pelot, R.P., Reid, S.A., Doan, J.B. and Rigby, W.A. Commercial Pack Investigations: Osprey Vector One Silhouette 70, Synkron Norrona Para Ranger 135L, and Dana Designs ArcFlex Astral Plane Load Carriage Systems Design Assessment using the APLCS Load Carriage Simulator. Contract #W7711-7-7384/001/SRV, (separate reports 50 pages each), 1997.

Bryant, J.T., Stevenson, J.M., Pelot, R.P., Reid, S.A., Doan, J.B. and Rigby, W.A. Commercial Pack Assessments: Ostrom Pack Prototype M1 Load Carriage System, Ostrom Pack Prototype Pack K1 Load Carriage System, PWGSC Contract #W7711-7-7384/001/SRV, (100 pages), 1997.

Morin E. Reid, S.A., Whiteside, R., Stevenson, J.M., Bryant, J.T. CTS Phase IIID. PWGSC Contract #W7711-7-7461/SRV-8-011, (50 pages), 1998.

2.3.2 Investigation of Sub-Systems: Load Carraige Vests and Fragmentation Vests.

One aspect of importance to the Clothe the Soldier System is the successful integration of the Load Carriage Vest (LCV) and the pack as well as the Fragmentation Vest. To accomplish this objective, a series of new outcome measures were generated; namely relative displacement of kit items in the LCV and compatibility of kit in the LCV and pack-based items with and without the fragmentation vest. Queen's was able to complete their assessments usually within three days of receiving the PLC system and completed their final reports within two weeks of delivery of the system. This rapid response allowed the designer to incorporate findings and recommendations into the design loop. In addition to testing the systems on the LC Simulator and LC Compliance Tester, Queen's APLCS Project Manager, Ms. Sue Reid, (M.Eng., P.Eng.) travelled to CFB Petawawa to observe human trials and to DND headquarters in Ottawa as part of the design team.

Technical Reports

Bryant, J.T., Stevenson, J.M., Pelot, R.P., Reid, S.A., Andrews, D. and Doan, J. Prototype Load Carriage Vest Design Assessment using the APLCS Load Carriage Simulator, PWGSC Contract # W7711-6-7356/001/SRV, (38 pages), 1998.

Reid, S.A., Stevenson, J.M., Bryant, J.T., Morin, E. Prototype Fragmentation Vest. PWGSC Contract # W7711-8-7463/001/SRV, (38 pages), 1998.

2.3.3 Investigation of Specific Design Features:

Over the course of the Clothe the Soldier Program, a number of design features have been investigated using the LC Simulator, LC Compliance Tester and Load Distribution Manikin. Each of these design questions has been handled quickly

and with a number of recommendations to the designer to make design decisions. The questions that were addressed were:

1) Effect of Back Pack Shoulder Strap Lower Attachment Point on the Load Distribution to the Torso.
2) Effect of Rods and No Rods in the Suspension System of the Pack
3) Effect of Different Shoulder Strap Contours on System compatibility and Shoulder Pressure Measurements

Technical Reports

Reid, S.A., Bryant, J.T., Morin E., Stevenson, J.M., Doan, J.E. Clothe the Soldier: Phase IIID: Effect of Back Pack Shoulder Strap Lower Attachment Point on the Load Distribution to the Torso, PWGSC Contract # W7711-7-7412/001/SRV, (19 pages), 1998.

Reid, S.A., Bryant, J.T., Morin E., Stevenson, J.M., Doan, J.E. Clothe the Soldier: Phase IIID: Effect of Different Shoulder Strap Contours on System compatibility and Shoulder Pressure Measurements, PWGSC Contract # W7711-7-7412/001/SRV, (29 pages), 1998.

Reid, S.A., Bryant, J.T., Morin E., Stevenson, J.M., Doan, J.E. Clothe the Soldier: Phase IIID: Effect of Lateral Rods and No Rods in the Suspension System of the Pack, PWGSC Contract # W7711-7-7412/001/SRV, (39 pages), 1998.

2.3.4 Investigation of the Penultimate Prototype of the Ostrom 'Clothe the Soldier' (CTS) System:

Prior to field testing of 50 systems with soldiers at CFB Gagetown, the complete penultimate system will be tested at in the Ergonomics Research Centre at Queen's University. It is anticipated that minor surface features may be adapted after the field trials but it is doubtful that these changes will affect the objective measures. The objective tests will include output measures from the LC Simulator, LC Compliance Tester and Load Distribution Tester on:

1) LCV alone
2) LCV and Ostrum Penultimate Pack
3) Gen III Frag Vest, LCV and Ostrum Penultimate Pack

The goal of these tests will be to use the Ostrom Penultimate CTS System as the baseline bench mark for all subsequent testing. The original database is poorer on many parameters because poorer LC systems were being evaluated. By using the Ostrom Penultimate Pack as the baseline, criteria will be set for the objective measures. Future pack evaluations will be compared to this system as the 'gold standard' of military systems.

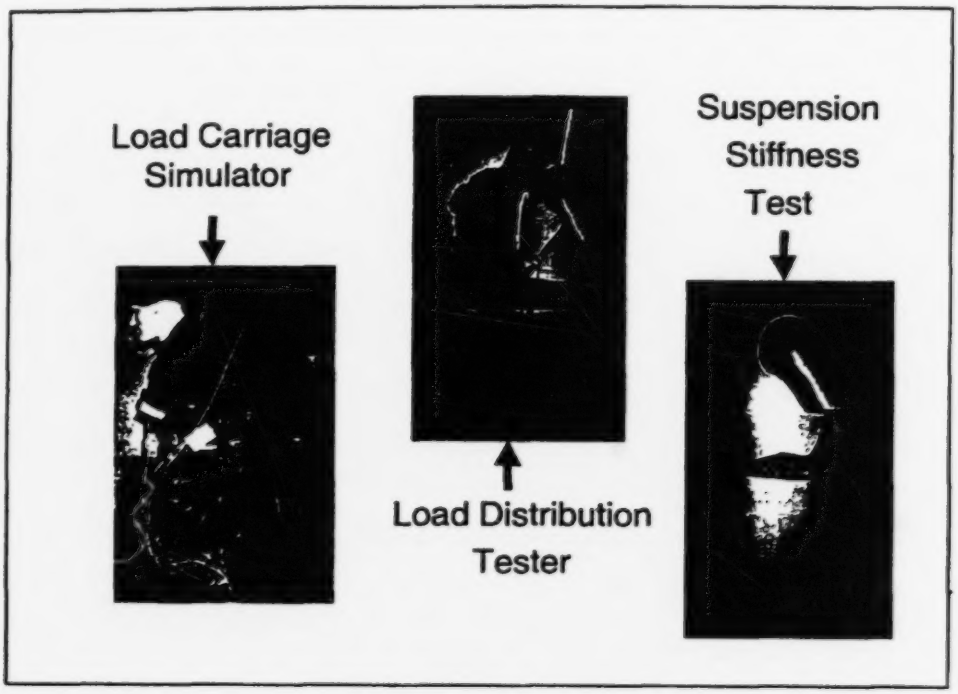
Technical Report

Morin E., Reid, S.A., Bryant, J.T., Stevenson, J.M., Doan, J.E. Clothe the Soldier: Phase IIID: Prototype Pack Biomechanical Testing of the Ostrum Penultimate CTS System, PWGSC Contract # W7711-7-7461/001/SRV, (39 pg), 1998.

3.0 Summary of Objectives of Phase IV of the IPCE Project

One goal of the PWGSC Contract # W7711-7-7520/A, called 'Phase IV' of the IPCE project was to provide DCIEM with unencumbered Load Carriage Assessment System and all necessary documentation to move the standardized assessment tools to DCIEM or another site. A second goal was to further develop our understanding of factors affecting load carriage, investigate specific factors that may limit future developments and develop the concepts for new tools that could help in future design phases. The objectives of each Section of the contract are summarized below. Each Section has been isolated into its own report and specific results will not be presented in this executive summary.

3.1 SECTION A: Executive Summary of Advancements in Personal Load Carriage Measurement Systems



The Executive Summary briefly identifies the items; namely, the LC Simulator, LC Compliance Tester and Load Distribution Manikin that are acknowledged by this report to be fully owned by DCIEM. The Executive Summary is also used to capture some of the essential features of 'work to date' including a listing of articles and presentations. Figures A3.1 – A3.3 are photographs of the three assessment tools (Figure A3.1a) LC Simulator; Figure A3.1b) LC Compliance Tester; and Figure A3.1c) Load Distribution Manikin).

3.2 SECTION B: Users Manuals and Equipment Items for Load Carriage Assessments

Section B provides DCIEM with user's manuals and a list of parts for the LC Simulator, LC Compliance Tester and Load Distribution Manikin. Although it is possible theoretically to understand how to operate and repair each assessment item by means of the manuals, it is advisable to contract for a technology transfer phase at the time of moving the equipment to another site.

Technical Report

Reid, S.A., Doan J.E. Stevenson, J.M. Section B: Users Manuals and Equipment Items for Load Carriage Assessments. PWGSC Contract # W7711-7-7420/A (45 pgs), 1998.

3.3 SECTION C: Phase II of a Biomechanical Model for Load Carriage Assessment

Section C provides and explanation and Phase II software for the current biomechanical model. This model is a design and evaluation tool which enables designers to input pack parameters and receive objective measures of pack effectiveness in terms of the resultant shoulder and lumbar spine forces.

Technical Report

Pelot, R.P., Rigby, A., Bryant, J.T., Stevenson, J.M. Section C: Phase II of a Biomechanical Model for Load Carriage Assessment. PWGSC Contract # W7711-7-7420/A (45 pgs), 1998.

3.4 SECTION D: Computer Database: Summary and Correlation of Load Carriage System Assessments

Section D contains the database of all previously collected data under both the IPCE and CTS programs. At the time of this report, 17 complete or partial

systems were collected using for the LC Simulator, LC Compliance and from First Assessment and Standardized Testing (FAST) Trials.

Technical Report

Doan J.E., Reid, S.A., Stevenson, J.M. Bryant, J.T., Morin E., Pelot, R.P. Section D: Computer Database: Summary and Correlation of Load Carriage System Assessments PWGSC Contract # W7711-7-7420/A (36 pgs), 1998.

3.5 SECTION E: Applicability of the F-Scan System for Human Pressure Assessments

The objective of Section E was conducted to understand the difficulties that would occur in attaching and calibrating the F-Scan sensors on human for in-situ testing. A method of attachment and four strategies of calibration were investigated.

Technical Report

Morin E., Reid, S.A., Bryant, J.T. Section E: Applicability of the F-Scan System for Human Pressure Assessments. PWGSC Contract # W7711-7-7420/A (27 pgs), 1998.

3.6 SECTION F: Phase II of Parametric Analysis of Advanced Personal Load Carriage Systems

Section F allows for greater understanding of relationships between design characteristics and the impact of these design features on the bearer, by two methods: the biomechanical model between the pack and bearer and mathematical contents model between items within the pack. Together they from the initial phase of a comprehensive load carriage optimization model that will allow designers and field personnel to understand the impact of certain loads or load locations on the bearer.

Technical Report

Pelot, R.P., Pinter, J., Rigby, A., Bryant, J.T., Stevenson, J.M. Section F: Phase II of Parametric Analysis of Advanced Personal Load Carriage Systems. PWGSC Contract # W7711-7-7420/A (45 pgs), 1998.

3.7 SECTION G: Analysis of Human Responses to Load Location in a Back Pack

The purpose of this study was to determine the effect of varying the centre of gravity of the load on physiological, biomechanical and subjective factors on experienced soldiers. Four load carriage strategies were studied with 22 soldiers bearing 36 kg in high medium and low load locations and in a load carriage vest.

Technical Report

Johnson, R.C., Pelot, R.P., Doan, J.E., Stevenson, J.M. Section G: Analysis of Human Responses to Load Location in a Back Pack. PWGSC Contract # W7711-7-7420/A (30 pgs), 1998.

Table 1. 0 Papers in Conference Proceedings (full papers in Appendix A)

1998 Doan, J.B., Stevenson, J.M., Bryant, J.T., Pelot, R.P., Reid, S.A. Developing a Performance Scale for Load Carriage Designs. ADesigning for Human Performance": Proceedings of the 30th Annual Conference of the Human Factors Association of Canada. p.239-243, 1998

1998 Rigby, W.A., Reid, S.A., Doan, J.B., Bryant, J.T., Stevenson, J.M. Design optimization of Load Carriage Suspension systems. . ADesigning for Human Performance": Proceedings of the 30th Annual Conference of the Human Factors Association of Canada. p. 221-226, 1998

1998 Rigby, W.R., Bryant, J.T., Reid, S.A., Doan, J.B., Pelot, R.P., Stevenson, J.M. Development and Validation of a Biomechanical Design Tool for the Evaluation of Personal Load Carriage: Phase II. Proceedings of the North American Congress on Biomechanics. Waterloo, ON pg.111-112, 1998.

1998 Rigby, W.A., Bryant, J.T., Reid, S.M., Doan, J.B. Stevenson, J.M. Analysis of load carriage systems using system compliance measures. Advances in Occupational Ergonomics and Safety, (edited, Kumar) IOS Press Inc., Virginia, p.308-311, 1998.

1998 Doan, J.B., Bryant, J.T., Reid, S.M., Stevenson, J.M., Rigby, W.A., Andrews, D. Function testing of military load carriage subsystems. Advances in Occupational Ergonomics and Safety, (edited, Kumar) IOS Press Inc., Virginia, p.707-710, 1998.

1998 Johnson, R.C. Doan, J.B., Stevenson, J.M. Bryant, J.T. An analysis of subjective responses to varying a load centre of gravity in a backpack. Advances in Occupational Ergonomics and Safety, (edited, Kumar) IOS Press Inc., Virginia, p.248-252, 1998.

TECHNICAL REPORTS:

1997a Pelot, R.P., Pintér, J., Stevenson, J.M., Bryant, J.T., Hall, C. and Day, J. Parametric Analysis of Advanced Personal Load Carriage Systems. Contract #W7711-5-7273/001 TOS (49 pages).

1997b Bryant, J.T., Stevenson, J.M., Pelot, R.P., Reid, S.A., Doan, J.B. and Rigby, W.A. Commercial Pack Investigations: Osprey Vector One Silhouette 70, Synkron Norrona Para Ranger 135L, and Dana Designs ArcFlex Astral Plane Load Carriage Systems Design Assessment using the APLCS Load Carriage Simulator. Contract #W7711-7-7384/001/SRV, (50 pages).

1997c Bryant, J.T., Stevenson, J.M., Pelot, R.P., Reid, S.A., Doan, J.B. and Rigby, W.A. Commercial Pack Assessments: Ostrom Pack Prototype M1 Load Carriage System, Ostrom Pack Prototype Pack K1 Load Carriage System, Contract #W7711-7-7384/001/SRV, (100 pages).

1997d Bryant, J.T., Stevenson, J.M., Pelot, R.P., Reid, S.A., Andrews, D. and Doan, J. Prototype Load Carriage Vest Design Assessment using the APLCS Load Carriage Simulator, Contract # W7711-6-7356/001/SRV, (38 pages).

1997e Bryant, J.T., Stevenson, J.M. Assessment of Load Adjusting in the Prototype Land Warrior Load Carriage System. Gentex Corporation, (23 pages).

1997f Bryant, J.T. Stevenson, J.M., Pelot, R.P., Reid, S.A. an Doan, J.B. Research and Development of an Advanced Personal Load Carriage System (Phase II and III). Contract #W7711-5-7273/001-TOS (260 pages).

1996a Stevenson, J.M., Bryant, J. T. Pelot, R.P., Morin, E. Research and Development of an Advanced Personal Load Carriage System (Phase II and III). DSS Contract # W7711-5-7273/001-TOS (7 seperate sections of ~ 75 pg/rpt).

1996b Stevenson, J.M., Bryant, J.T., and Reid, S.A. and Pelot, R.P. Validation of the Load Carriage Simulator: Research and Development of an Advanced Personal Load Carriage system: Section D (Phase 1). DSS Contract #W7711-4-7225/01-XSE (44 pgs).

1995a Pelot, R.P., Stevenson, J.M.S., Reid, S., Barrick, C.M., and Day, J. Background Document for Advanced Personal Load Carriage Systems for Canadian Armed Forces. DSS Contract # W7711-4-7225/01 (112 pgs).

1995b Stevenson, J.M., Bryant, J.T., DePencier, R.P., Pelot, R.P., and Reid, J.G. Research and Development of an Advanced Personal Load Carriage System: Section A, B, C (Phase I). DSS Contract # W7711-4-7225/01-XSE 29 (350 pgs).

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14. ABSTRACT

(U) The Defence and Civil Institute of Environmental Medicine (DCIEM) contracted Queen's University to assist in the research and development of an Advanced Personal Load Carriage System (APLCS) in support of two Canadian Forces Soldier Modernization Programs: major crown project D6378 called Integrative Protective Clothing and Equipment (IPCE), and major crown project L2646 called Clothe the Soldier (CTS) Project. In 1995, Queen's University undertook to develop standardized assessment tools as a cost effective and reliable method by which various load carriage equipment designs and components could be tested, evaluated and approved for further military evaluations with representative users in the field. Under the IPCE project, Phases I-III involvement primarily development and validation of the measurement system. Further testing took place to evaluate and improve the prototype CTS load carriage system, add to the research data base and enhance knowledge of pack designs. Each of these projects will be described briefly with relevant outcomes identified. The current contract entitled: Research and Development of an Advanced Personal Load Carriage Measurement System: Phase IV was to improve measurement components and provide sole source ownership to DCIEM, and to develop a further understanding of specific factors that affect load carriage ability. The purpose of the Executive Summary Report is to summarize and document work to date so that DCIEM is aided in the decision-making process for future developments in the area of load carriage.

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15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) load carriage; biomechanical measurement; standardized assessment tools; biomechanics; load bearing equipment